APPENDIX A: SIGNAL FIELD STRENGTH COMPUTATIONS

Field strength is measured in dBµV/m as seen by the receiving antenna. This is calculated from the peak-power value and the antenna-correction factor using the following equations:

$$G_{dB_i} = -29.79 + 20\log_{10}(f_{MHz}) - ACF, \tag{A1}$$

where G_{dB_i} is the gain of the antenna in dBi, f_{mHz} is the frequency in MHz, and ACF is the antenna correction factor in dB;

$$A = \frac{\lambda^2 * 10^{\frac{G_{dB_i}}{10}}}{4\pi}, \tag{A2}$$

where A is the aperture of the antenna in units of m^2, and λ is the wavelength of the carrier frequency in meters;

$$\lambda = \frac{c}{f_{Hz}}, \tag{A3}$$

where c is the speed of light in m/s (3e8 m/s), and f_{Hz} is the carrier frequency in Hz;

$$P_d = \frac{P_{m(watts)}}{A}, \tag{A4}$$

where P_d is the power density in watts/m^2, and $P_{m(watts)}$ is the power in watts measured at the output of the antenna;

$$E_{dB(\frac{\mu v}{m})} = 20 * \log_{10}\left(1e6 * \sqrt{P_d * 377}\right), \tag{A5}$$

where $E_{dB\left(\frac{\mu v}{m}\right)}$ is the E field in dBµV/m measured at the antenna, and 377 is the impedance of free space measured in ohms.

APPENDIX B: NOISE FIGURE AND SENSITIVITY COMPUTATIONS

For a multistage amplifier that has stage power gains G_1, G_3, G_3,... (linear form), and stage noise figures F_1, F_3, F_3,... (linear form), respectively, the overall noise figure is [1]

$$F = F_1 + \left[\frac{(F_2 - 1)}{G_1}\right] + \left[\frac{(F_3 - 1)}{G_1 G_2}\right] + \cdots \tag{B1}$$

The measurement system seen in Figure 9, has a single stage gain of 22.4 dB (Mini-Circuits amplifier) with a typical noise figure of 2.9 dB. Cable losses and the insertion loss of the low pass filter are negligible. The noise figure of the spectrum analyzer is 31 dB. From Equation (B1), the overall noise figure of the system is 9.6 dB.

The bandwidth and overall noise figure of the system determine the smallest signal that can be detected; it is computed from the following equation:

$$NP = -174 + 10 \log_{10}(B) + F_{dB} , \tag{B2}$$

where *NP* is the noise power in dBm, -174 is the thermal noise in a 1-Hz bandwidth at room temperature (300° K), *B* is the bandwidth of the system in Hz, and F_{dB} is the overall noise figure of the system in dB. The quantity *NP* is the minimum signal power that can be detected at the output of the antenna. In this case, the bandwidth of the system is 300 Hz. Therefore, using Equation (B2), *NP* is calculated to be -139.6 dBm, or expressed in watts,

$$NP = \frac{10^{\left[\frac{-139.6}{10}\right]}}{1e3} = 10.96e-18 \ . \tag{B3}$$

Knowing *NP*, one can calculate the sensitivity of the system at the input to the antenna using Equations (A1) through (A5) (see Appendix A). Assuming a typical carrier frequency of 300 kHz and the corresponding antenna-correction factor of 40.5 dB, the minimum power density at the input to the antenna must be 16.18e-15 watts/m^2 in order to be detected. This corresponds to a field strength of 7.85 dB µv/m.

REFERENCE

[1] F.G. Stremler, *Introduction to Communication Systems*, Reading, Massachusetts: Addison-Wesley Publishing Company, 1997, pp. 173-174.

APPENDIX C: CORRECTION FACTORS FOR THE EATON 94592-1 ANTENNA

Table C-1 lists the antenna correction factors for the Eaton 94592-1 monopole antenna used during measurements. The antenna was measured to an absolute accuracy of 2 dB.

Table C-1. Antenna Correction Factors

Frequency (kHz)	**Antenna Correction Factor (dB)**
285.0	41.2
287.0	41.2
289.0	41.0
291.0	40.9
293.0	40.9
295.0	40.7
297.0	40.7
299.0	40.6
301.0	40.5
303.0	40.5
305.0	40.4
307.0	40.4
309.0	40.4
311.0	40.4
313.0	40.2
315.0	40.1
317.0	40.1
319.0	40.1
321.0	40.0
323.0	39.9
325.0	39.9

APPENDIX D: COMPUTATION OF EXPECTED ELECTRIC FIELD STRENGTH

For a known power into a transmitting antenna and a given antenna efficiency, the expected signal strength in dB µV/m can be determined at a specified distance from the transmitter. Assuming the signal is radiating isotropically into a hemisphere (see Figure D-1), the power is evenly distributed over a surface equal to $2\pi r^2$ (where r is the distance from the transmitter in meters). The power density at the receiver expressed in watts/m^2 can be determined by

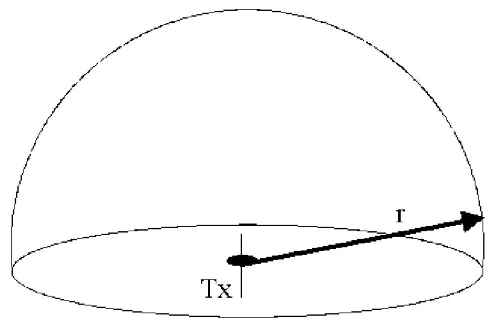

Figure D-1. Signal radiating isotropically into a hemisphere.

$$P_d = \frac{P_t e}{2\pi r^2}\,, \qquad \text{(D1)}$$

where e is the efficiency of the transmitting antenna and P_t is the input power.

The electric field E in dB µV/m is determined by

$$E = 20\ \log_{10}(1e6\ \sqrt{P_d\ 377})\ , \qquad \text{(D2)}$$

where 377 is the impedance of free space measured in ohms.

As an example, a transmitter with an antenna efficiency e between 15 and 20% and signal power P_t into the antenna of 1000 W, the expected power density P_d at 10 km would be between 238.7e-9 and 318.3e-9 watts/m^2 (Equation D1). The expected electric field strength E at the same distance is between 79.5 and 80.8 dB µV/m (Equation D2).